

# TRAVELLING IONOSPHERIC DISTURBANCES IN THE *F* REGION

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## *Summary*

Observations of the horizontal movements of travelling ionospheric disturbances recorded on a single radio frequency from April 1948 to March 1957 are analysed for seasonal and diurnal variations of occurrence and of direction and speed of travel. Recording was mainly in daylight hours but some limited night results are included. The average number of disturbances recorded was six per day over the period. Observing accuracy and significance of the deduced data are discussed. The frequency of occurrence has a diurnal variation with a marked midday maximum and a seasonal variation with minima at the equinoxes.

The monthly means of direction of travel show a consistent seasonal change from 30° in winter to 120° in summer with a small corresponding change in mean speed from 8 km/min in winter to 7 km/min in summer.

The monthly mean diurnal variation of directions was consistent from 1950 to 1954 but has shown a marked change in the last two summers. Winter directions by day are mainly in the north-east quadrant and have a mean day-time drift towards the north but at night they are predominantly in the north-west quadrant. Summer day-time directions were mainly in the south-east quadrant until December 1956; since then they have tended to the south-west after noon, reverting to the south-east about midnight.

Diurnal variation of speed is of the same order as the seasonal change.

## I. INTRODUCTION

Previous papers from this laboratory have described some of the characteristics of travelling disturbances in the *F* region of the ionosphere (Munro 1950) and some of the effects they produce on the common types of ionospheric records (Munro 1953*b*). Some preliminary information was also given on seasonal and diurnal variations in the direction and rate of travel (Munro 1950, 1953*a*).

Observations have now continued for a period of 9 years and sufficient information is available for significant statistical examination of a number of features of the occurrence and movements of the disturbances.

The present paper deals with horizontal movements of disturbances as observed on a single radio frequency.

## II. RECORDING TECHNIQUE

The observing system has been described previously (Munro 1950). Three similar pulsed transmitters operating on a common frequency are spaced about 40 km apart at the apices of a triangle. The transmitters are pulsed successively so that the echo signals from all three may be displayed simultaneously on a

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cathode-ray oscilloscope and recorded continuously on photographic film. The effective separation of reflection points is about 20 km, which has proved to be the optimum, since for smaller distances the time difference is too small, whilst for greater distances individual disturbances are not always identifiable at all points. The frequency of 5.80 Mc/s, which has been used most often, has been found very suitable as at least one ray reflected from the  $F_2$  region is normally present. Lower frequencies have occasionally been used, particularly for night observations. Higher frequencies have not been much used, as most of the observations have been in a low sunspot period.

Recording has usually been carried out at two sites. This reduces loss of data due to instrumental failure and also permits emphasis on different features at the two points; for example, at the base station, both  $E$  and  $F$  echoes are recorded for comparison, while at a field station, where the noise level is lower, the  $F$  echoes are recorded in greater detail by the use of higher receiver sensitivity and a more open time-base scale.

Virtual height recording using intensity modulation of the cathode-ray oscilloscope beam has been found the most useful for regular observations. The equipment used is also capable of recording continuously either intensity variations or phase-path changes; these facilities have been used occasionally for special observations not discussed in the present paper.

Recording has been carried out mostly by day from approximately 0700 to 1700 hr. This interval covers the period of most frequent occurrence of disturbances.

Regular observations began in April 1948 and have continued with only minor interruptions.

Night-time observations have been made for limited periods, as will appear in the text.

### III. OCCURRENCE OF DISTURBANCES

The types of disturbance manifestations observed on records have been described in previous papers (Munro 1950, 1953*b*). In the statistical examination which follows in this section we shall consider mainly complexities or abrupt changes in virtual height (which are actually very small complexities) as these are interpretable in terms of geometrical optics and are much more precise and reliable indications of disturbances than virtual height maxima and minima or ray "cross-overs", which are sometimes used for detection of movement in the absence of complexities. Variations of intensity may also be used as indications of disturbances, but they are found to be less reliable than complexities because additional variations due to absorption and focusing in lower regions may confuse results. In this section records from only one station are considered and the appearance of a complexity on at least one trace is listed as an occurrence of a disturbance.

#### (a) *Frequency of Occurrence*

These disturbances are of quite frequent occurrence; for example, the average number recorded per day in the years 1951–1956 was approximately six. The number observed varies considerably from day to day. Ease of

observation depends to some extent on the ionization gradient at the time, but this does not account entirely for the day-to-day fluctuations. There do appear to be "quiet days" when disturbances are either absent or very small, and there may be several such days in succession followed by one or more "active" days. The nature of these variations is shown in Figures 1 (a) and 1 (b) which give the number observed each day during the months of July 1955 (winter) and January 1956 (summer) respectively. The mean number per day in each month for the years 1951-1956 is shown in Figure 1(c).

It will be noticed that there is a rough periodicity present in curves (a) and (b).

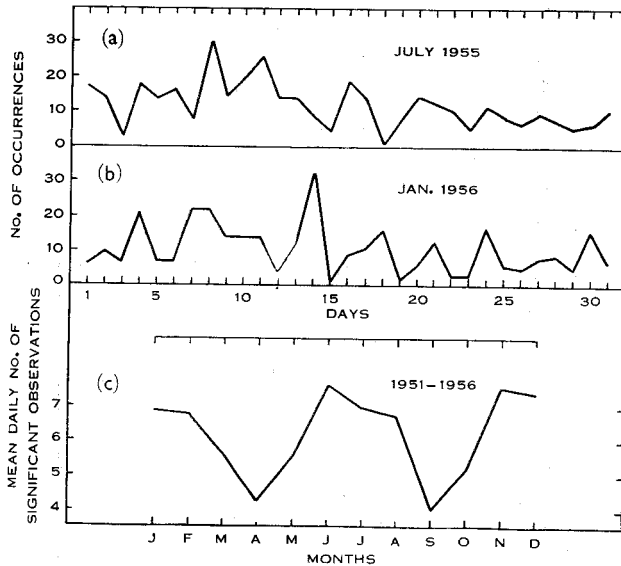


Fig. 1.—Frequency of occurrence of travelling ionospheric disturbances. (a) Day-to-day variations, July 1955; (b) day-to-day variations, Jan. 1956; (c) mean annual variation 1951-1956.

#### (b) Diurnal Variation of Occurrence

(i) *Day-time*.—The frequency of occurrence of observable disturbances has a marked diurnal variation. The mean variation for each month of the years 1950-1953 is shown in the histograms of Figure 2. The ordinate scale is numbers per hour when conditions were satisfactory for observations. This correction was necessary since the curves would otherwise be distorted because of blanketing by  $E_s$ , which has a morning maximum in summer (Harvey 1955). The lower values shown in December and January are the uncorrected ones.

It will be seen that in winter there is a single peak at 1130-1230, but at the equinoxes there are two peaks, before and after midday. This is most marked in September. These peaks are significant since they recur each year, as shown in Figure 3.

Other monthly distributions also repeat from year to year.

(ii) *Night-time*.—Night-time observations have been taken only for a few relatively short periods and the data are insufficient for satisfactory statistical treatment. In general there seems to be an increase in occurrence of disturbances in the middle night hours.

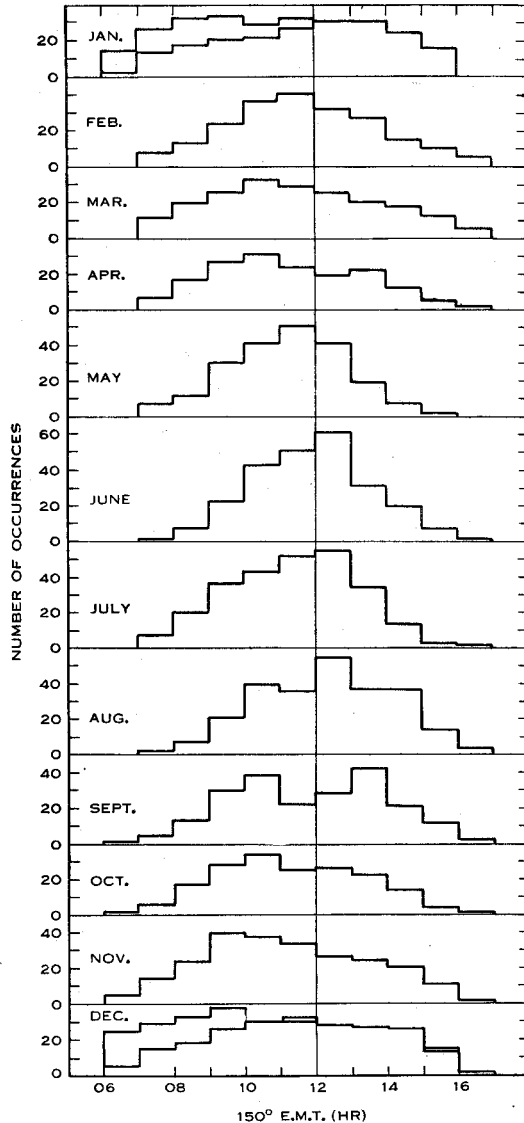


Fig. 2.—Seasonal variation in diurnal distribution of occurrence of disturbances, July 1949 to April 1953.

#### IV. MOVEMENT OF DISTURBANCES

For the deduction of direction and speed of movement it is necessary that the manifestation of a disturbance on a particular ray (“o” or “x”) should be recorded for each of the three transmissions on at least one record. This does

happen in most cases. There must also be no possible ambiguity in correlation of complexities on the different traces. These requirements have been fulfilled for all the data used in this section.

(a) *Treatment of Records and Data*

(i) *Analysis of Records.*—The echo traces corresponding to the three transmitters appear on the film records one above the other so that the time differences in the occurrence of disturbances at the three reflection points are readily observable and unaffected by any errors in actual time of occurrence. Examples of the different types of discontinuity have been shown previously (Munro 1953*b*). To the practised eye they are easily discerned, even when quite small. These discontinuities are far the most frequently observed features, but where none are present peaks or dips in virtual heights and cross-overs of the *o* and *x* ray traces are also used as indicators of disturbances.

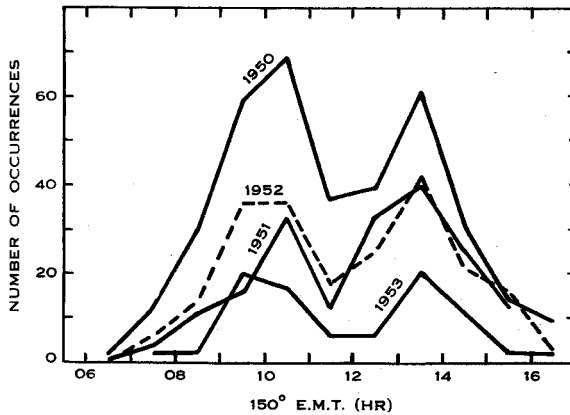


Fig. 3.—Diurnal distribution of occurrence of disturbances in September 1950-1953.

From the time differences in occurrence, the direction and speed of horizontal movement are then determined from tables which have been computed for the particular group of stations, and listed against the earliest time of occurrence.

In the analyses which follow, all such listed data have been used without any form of discrimination.

(ii) *Significance of Data.*—The significance of the analytical results obtained will depend on the quantity and variability of the data, so this aspect requires some detailed consideration.

Assuming that the apparent directions of movement are true directions (this will be discussed more fully in the next section) the accuracy with which they may be determined will depend for a given system on (a) the accuracy with which the time differences of arrival of a disturbance at an observing point may be measured and (b) the speed of travel of the disturbance.

In practice, the times of occurrence of the more clearly defined disturbances are read to the nearest  $\frac{1}{4}$  min; others, less clearly defined, to the nearest  $\frac{1}{2}$  min



of movement. It will be seen that, where times are recorded to the nearest  $\frac{1}{4}$  min, the lower limit of directional accuracy for normal velocities will be of the order of  $5^\circ$ .

(b) *Variability*

(i) *Daily Scatter*.—It has been mentioned previously (Munro 1950) that the observed directions and speeds may show considerable scatter in a single day. The limitations of the observing system have been discussed in an earlier section, but the variations are frequently greater than can be accounted for by such errors. Moreover, the directions may show regular drifts. Typical examples of the amount and variability of this scatter may be seen in Figure 5.

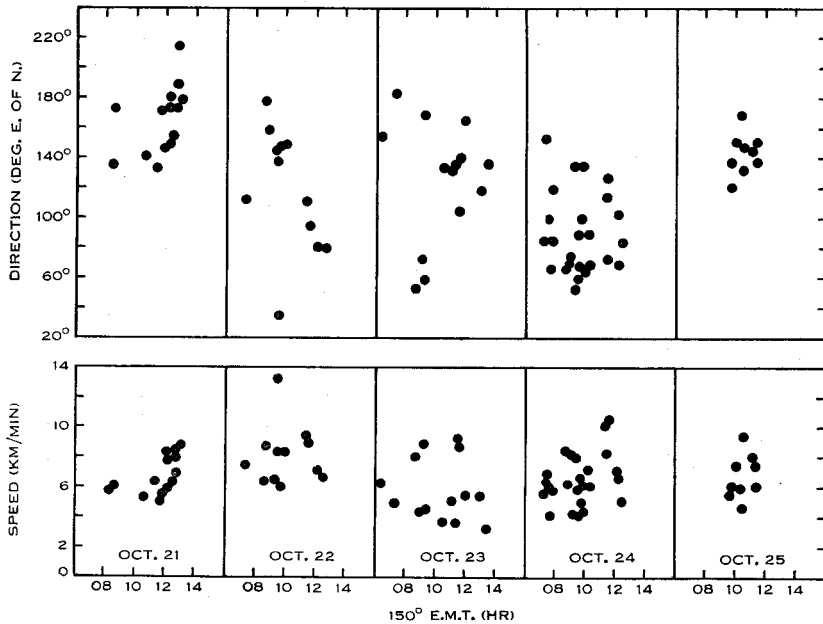


Fig. 5.—Day-to-day variations in direction and speed of movement, October 21–25, 1951.

The method of deducing directions assumes that each disturbance has a straight front. Curvature of the front could introduce an error in the deduced direction. In addition, any fluctuation local to one reflection point may bias the observation at that point. It has been apparent for some years that there are at least two scales of irregularities in the *F*-region reflections, one which produces fading periods of the order of seconds, and the other, of the type we are considering here, which gives fading periods of the order of minutes. This has been clearly confirmed by directional observations recorded by Bramley and Ross (1951). These smaller irregularities will be less liable to cause errors in deduced direction when complexities are observed than in the case of peaks or cross-overs, since they will affect the magnitude of a complexity without altering its position (or time of occurrence), but they may change the position (or time) of a retardation peak.

The tabulations will also tend to give some preferred directions owing to discontinuities in timing. For example, at speeds greater than 5 km/min the table as seen from Figure 4 gives no readings between 75 and 78°, and, omitting  $\frac{1}{4}$  minutes, no readings between 70 and 78°; and the gap increases with speed.

These limitations are taken into account in the statistical analyses which follow.

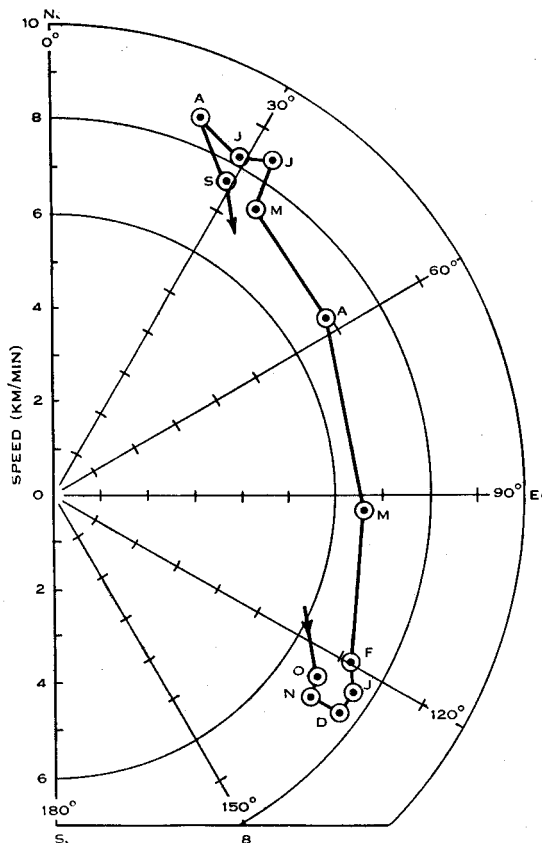


Fig. 6.—Seasonal variation of monthly median velocities.  
Mean of 8 years: April 1948 to March 1956.

It should be borne in mind that the apparent direction, as observed in this way, will be the horizontal component of movement normal to the front of the disturbance.

(ii) *Day-to-day Variations.*—It has been mentioned earlier that the directions may vary considerably from day to day. This is particularly so at the equinoxes. Plots of all directions and corresponding speeds recorded each day for a period of 5 days are shown in Figure 5. It is obvious from inspection that the daily means of direction and speed vary appreciably.

Simultaneous observations at two points, Sydney and Perth (Price 1955), which have almost the same latitude but are separated by 3500 km, suggested



that the day-to-day variations in number of occurrences and direction of movement may have a longitude variation with an apparent lag in occurrence of approximately a day in this interval of  $40^\circ$  of longitude.

(c) *Seasonal Variation—Day-time*

(i) *Mean Directions and Speeds.*—The mean annual variations in monthly medians of apparent velocity of disturbances over a period of 1 year were shown in a previous paper (Munro 1950). Data now available cover a continuous period of 9 years, and the means of the monthly medians for 8 years are shown in Figure 6. The compact summer and winter groups appear very clearly, with an abrupt change in direction from September to October and a more gradual one from February to May; March and April being transitional months. Some additional features become more evident if the directions and speeds are considered separately and in more detail.

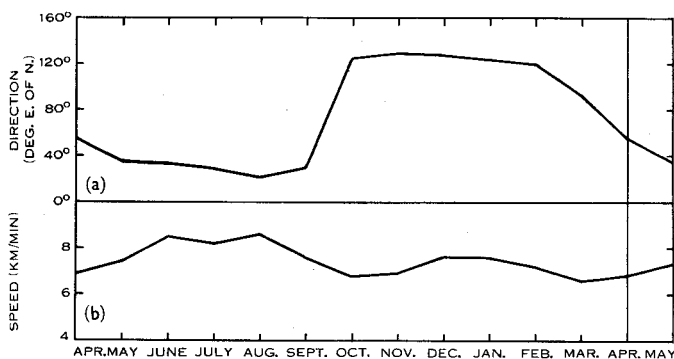


Fig. 7.—Monthly mean values of (a) direction of travel and (b) speed of horizontal movement, for the period April 1948 to May 1956.

In Figure 7 the data of Figure 6 are replotted to show in (a) the variation of the mean of the monthly medians of direction and (b) the corresponding variation in horizontal speed. The seasonal changes in direction are clearly shown in (a); and in (b) it will be seen that there is a definite maximum of speed in midwinter (June, July, and August) and a smaller maximum in midsummer. The minima occur in October and March, coinciding with the equinoctial changes of direction and also with the minima of occurrence shown in Figure 1 (c).

The general features of these annual variations have repeated from year to year with some secondary variations. The deviations from the mean curves are shown in Figures 8 (a) and 8 (b). In Figure 8 (a) it will be seen that, although there is some scatter of monthly values, which is greatest in October and February and greater in summer than in winter, no marked deviation from the mean direction persists for more than a few months. In Figure 8 (b) the year which shows the greatest abnormality is 1949–1950, where the speed was a record high value in June but fell to a record low value in July and continued low for the rest of the year, giving record lows for both minima. December 1948 shows a record summer maximum, so that we really have two high maxima in 1948

and 1949 followed by two low minima in 1949 and 1950. If we follow this clue and observe the total seasonal variations, that is, maxima and minima only, we get the result shown in Figure 9. It will be seen that the winter

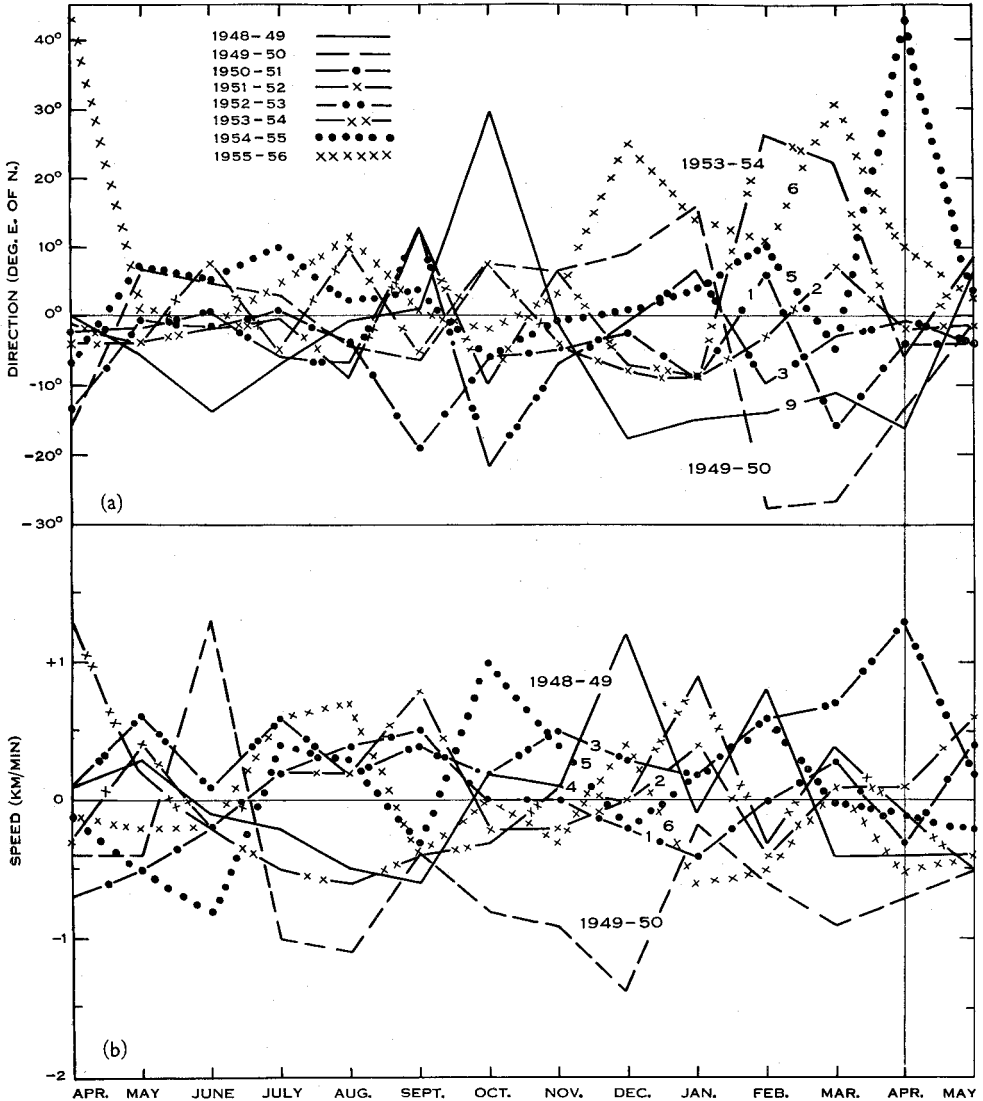


Fig. 8.—Deviations from mean of monthly medians of (a) directions, and (b) speeds. Period: April 1948 to May 1956.

maximum is greatest in 1949 and least in 1953, while the summer maximum is least in 1949-1950 and greatest in 1953. The variations for both equinoctial minima are similar, with trends roughly following the inverse of the summer maximum. 1953 happens to be the year of sunspot minimum, which may have

some significance, but rising values of winter maximum have not been maintained in 1956, which is a year of rapidly increasing sunspot numbers.

(ii) *Distribution of Directions and Speeds.*—(1) *Direction.*—It has been mentioned previously (Munro 1950) that the scatter of directions varies from month to month, being a minimum in midwinter. This has been confirmed in subsequent observations and merits closer examination. In Figure 10 are shown histograms of observed directions for three months—January (summer), March (equinoctial), and July (winter)—for each of three successive years—1951, 1952, and 1953. It will be seen that the pattern repeats its general form from year to year. This applies in all months, so the monthly values for 6 years have been lumped in Figure 11 to give the mean monthly distribution.

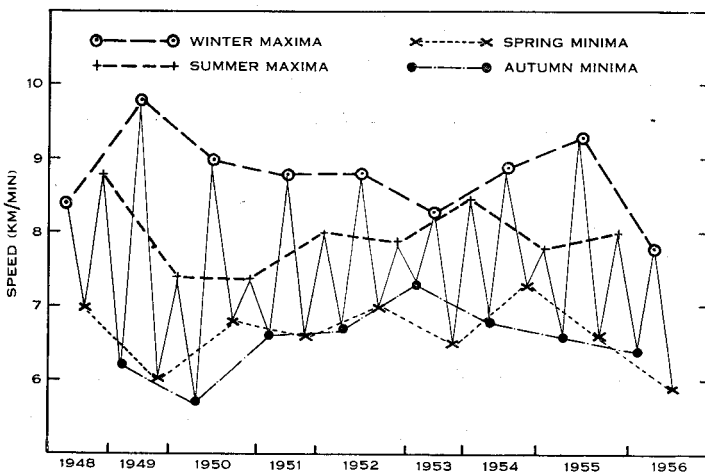


Fig. 9.—Variations in maxima and minima of monthly medians of speed.

This presentation suggests that there are two main groups of directions and that the seasonal drift is really due to a shift of emphasis from one group to the other. The winter group is the more compact and both groups are present in the transitional months, but the total spread for each month is approximately constant—about  $180^\circ$ .

The abrupt change from September to October and the more gradual one in March, April, and May is again apparent. The greater scatter in directions in the summer months, particularly December, is seen to be due to the indefinite peaks rather than to greater total spread.

(2) *Speeds.*—The monthly mean distribution of speeds is also consistent from year to year; in Figure 12 the monthly averages over 6 years are shown as histograms.

Very few values below 3 km/min are recorded, though there is no technical reason why they would not be observed. In all, 54 have been recorded in 7 years, ranging from 1.9 to 2.9. Values greater than 15 km/min are relatively scarce and those recorded are considered doubtful since the possible errors became great at speeds above 10 km/min, as can be seen in Figure 1.

The whole of the data for this period, comprising 13,642 values, are replotted on log-probability paper in Figure 13 with, for comparison, those for July, a month of maximum mean speed (1299 values) and those for March, a month of minimum mean speed (1029 values). It will be seen that in each case the points approximate closely to a straight line except for values above 90 per cent. As these are all for speeds greater than 10 km/min it is obvious that the deviation

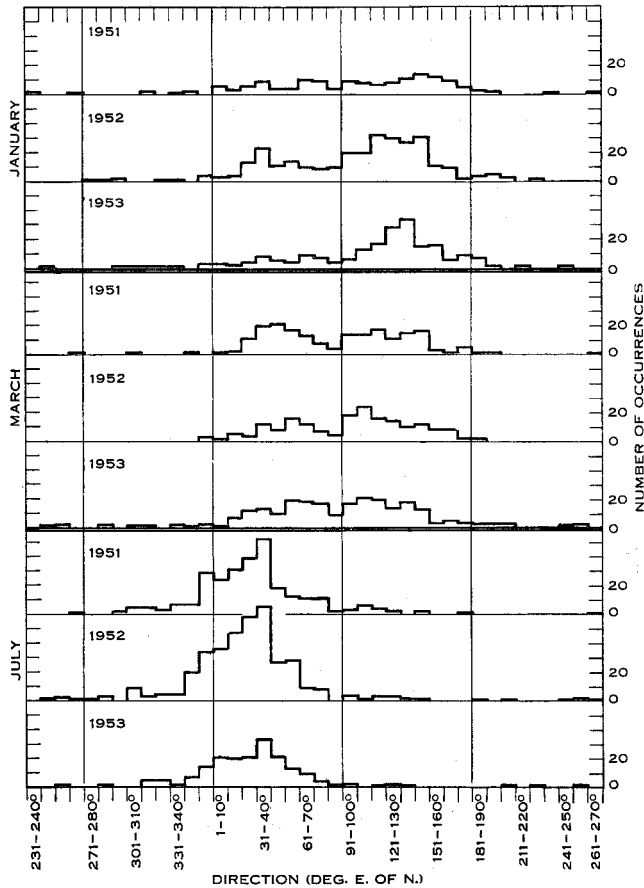


Fig. 10.—Distribution of directions during January, March, and July in the years 1951–1953.

is the result of biasing due to the method of computing speeds; it can be seen in Figure 4 that the possible errors are greatest at high speed and increase with each increment of time.

It appears therefore that the distribution is a normal Gaussian one.

#### (d) Diurnal Variation

It has not been possible to observe disturbances consistently over the full 24 hr. In the evening period of some 4 hr centred on sunset observable disturbances are rare, and interference from commercial radio stations, and

from atmospherics in summer, makes satisfactory recording difficult. In the early morning the penetration frequency is a minimum and was below 5.8 Mc/s for most of the years of observation; and it also seems to be a quiet period for disturbances. Recording has therefore been most consistent from 0730–1730 hr.

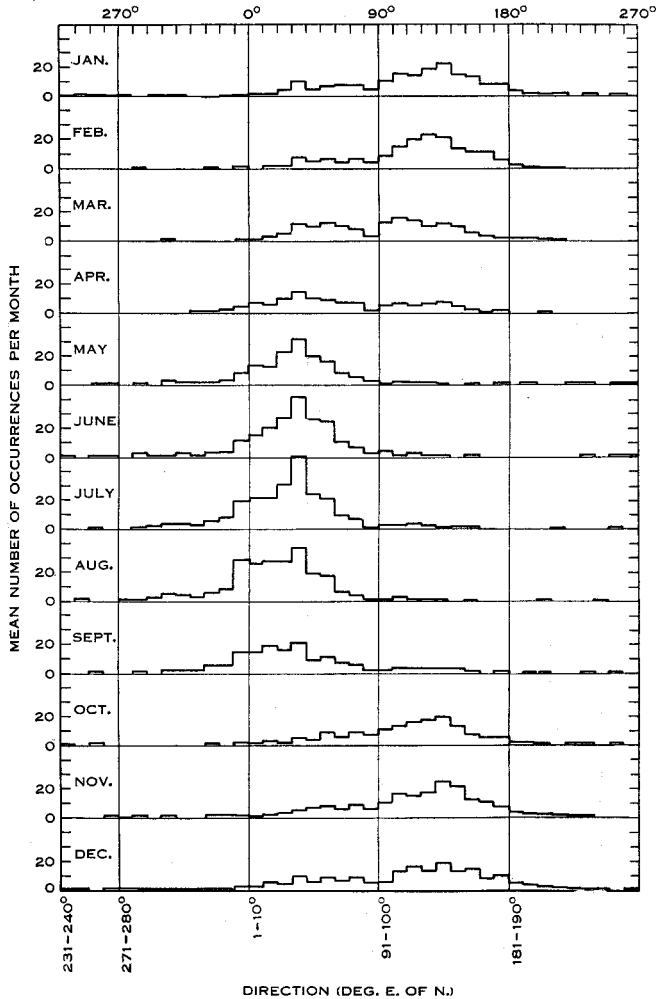


Fig. 11.—Distribution of directions for each month. Mean of years April 1950 to March 1956.

The night-time observations have been more in the nature of samplings during the most profitable periods but they have provided some significant results. These day and night observations will be considered separately.

(i) *Directions.* — (1) *Winter day-time.* — A definite drift in direction of movement during the period 0900 to 1500 hr in June was previously reported for the years 1950–1952 (Munro 1953a) and this has been repeated closely in subsequent years, the greatest deviation being in 1956. Even more consistent results

are evident in May, July, and August. The mean of the medians for each of these four winter months in the years 1950–1956 are shown in Figure 14. The obvious feature is a steady and consistent drift towards the north.

(2) *Winter night-time.*—Night observations were taken on 22 nights on a frequency of 2.28 Mc/s in June 1953, during the hours 2030–0200. Features observed were mostly branches from the main trace, which we interpret as a

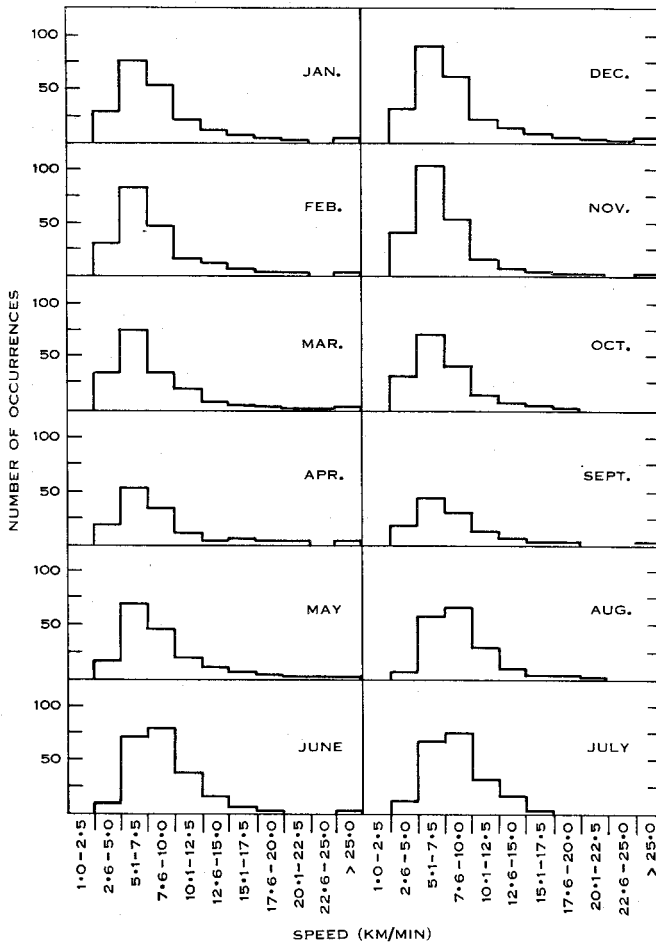


Fig. 12.—Distribution of speeds. Mean number of occurrences for each month of the year: period 1951–1956.

night-time version of a Y type anomaly (Munro 1953b), and there were some Z type anomalies and some sudden height changes; the results are shown in Figure 15. It will be seen that the directions are predominantly in the north-west-quadrant with a suggestion of a mean drift toward north about midnight.

(3) *Summer day-time.*—In summer over the years 1949–1954 no very definite diurnal variation was apparent, the hourly means being consistently close to 120°. In the 1955–56 summer, however, there were indications of a drift towards the

south in the afternoon, and in the 1956-57 summer the diurnal variation for November, December, and January was completely changed, showing a marked drift to the south and west. The contrast is shown in Figure 16 in which (a) shows the diurnal variation of mean hourly values for the months of November, December, and January in the years 1951-1954 and the maximum deviations from the mean values, while (b) shows the values in 1956-57.

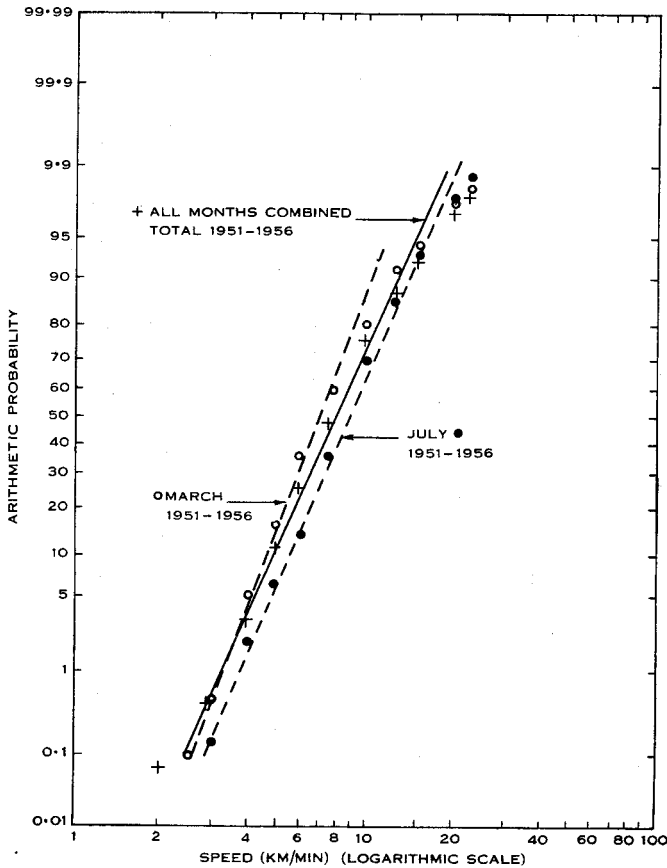


Fig. 13.—Distribution of speeds (probability plot).

Examination of directions recorded each day showed that during the earlier years there might be a definite drift of direction evident on a particular day but the direction of drift was not consistent from day to day. As an example the results for three consecutive days, December 5, 6, and 7, 1952 are shown in Figure 17, where it will be seen that there was an anticlockwise drift on the 5th, none on the 6th, and a clockwise drift on the 7th. There were also, in the earlier years, some directions recorded in the south-west section, mostly in the afternoon, but these were not sufficient to appreciably affect the monthly median and the number fell to a minimum in 1952-53.

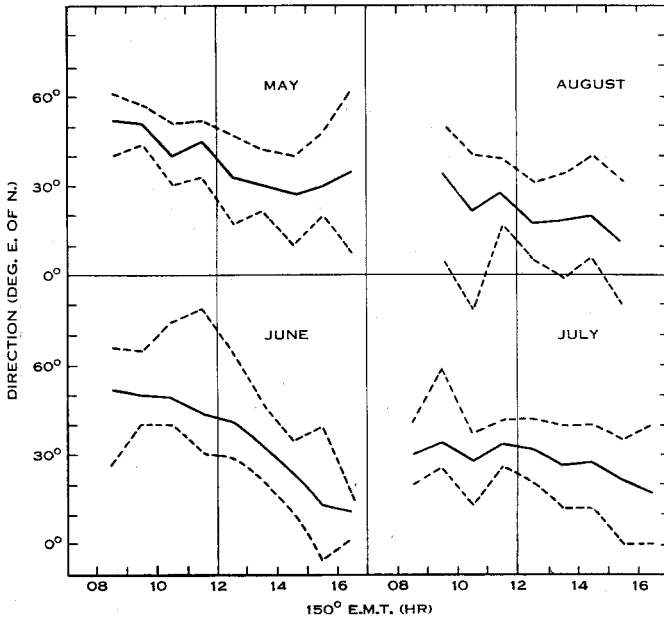


Fig. 14.—Mean day-time diurnal variation of direction in May, June, July, and August, 1950-1956. Broken-line curves show extreme values.

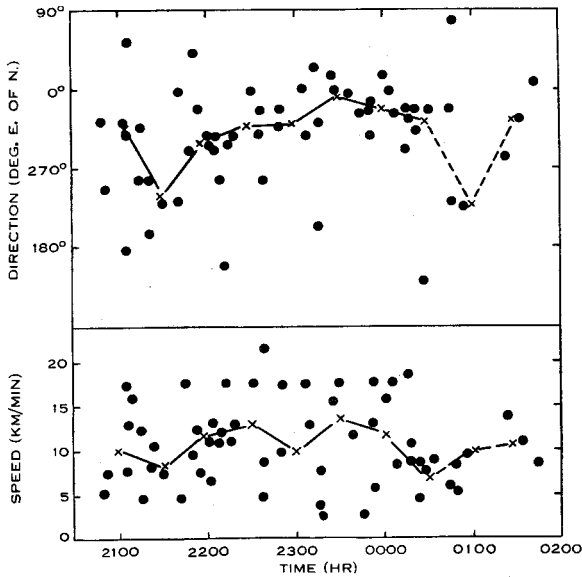


Fig. 15.—Diurnal variation of direction and speed, winter night (June 1953).



In November 1955 the midday reversals became more frequent and in December 1955 they showed a very marked increase. The difference between the morning and afternoon directions is emphasized in Figure 18 : (a) shows the directional distributions before and after noon and it will be seen that the great

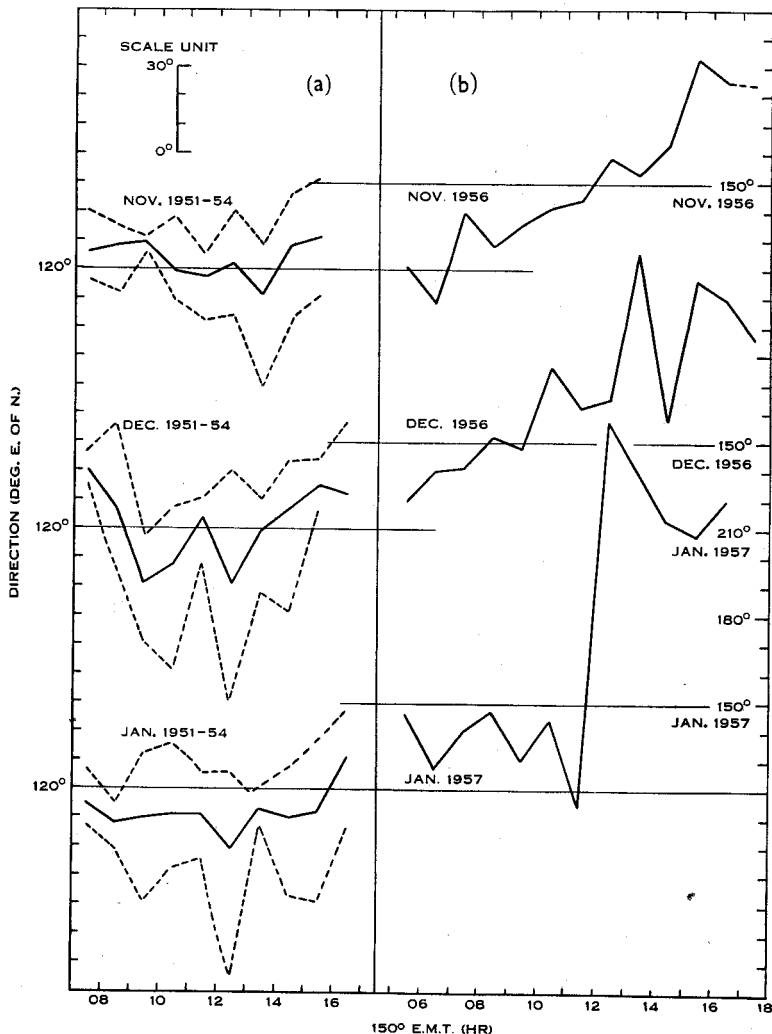


Fig. 16.—Diurnal variation in direction of movement : (a) Nov., Dec., Jan., 1951-1954 (broken line curves show extreme values); (b) Nov., Dec. 1956 and Jan. 1957.

majority of easterly directions occur in the morning and of westerly directions in the afternoon ; (b) shows the time distribution of occurrences from 0 to 190° and from 191 to 260°, 190° being the approximate magnetic meridian direction. The easterly peak of occurrence is between 10 and 11 hr and the westerly peak between 13 and 14 hr.

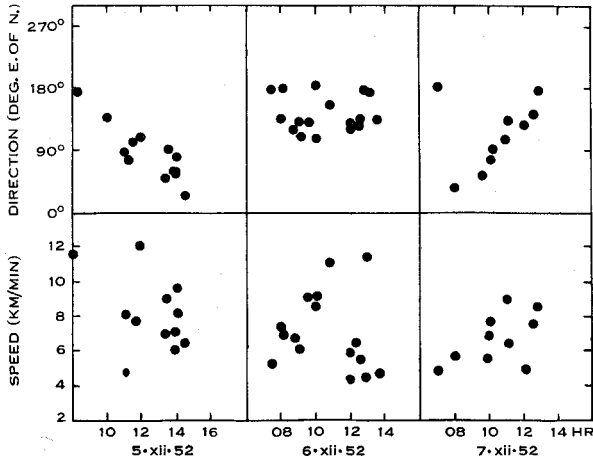


Fig. 17.—Diurnal drift of directions (Dec. 5, 6, 7, 1952).

(4) *Summer night-time.*—In the summer 1956–57, owing to the increased penetration frequencies and improved observational techniques, it has been possible to continue the observations on 5.8 Mc/s from 22 hr each night right through the morning and until 18 hr the next day.

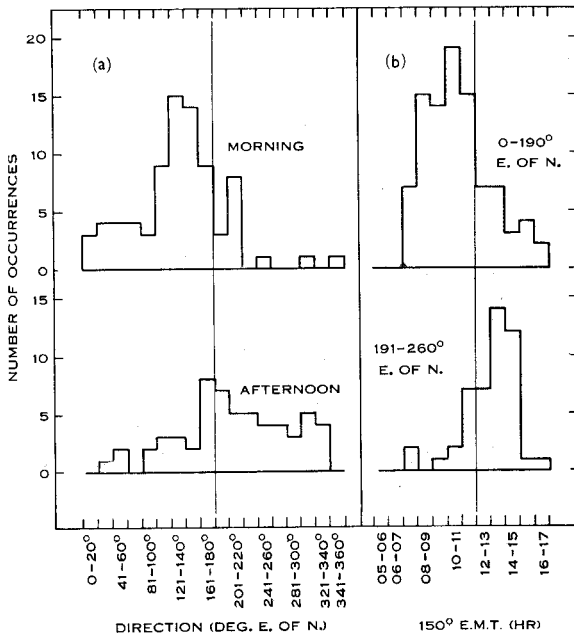


Fig. 18 (a).—Directional distribution of morning and afternoon observations.

Fig. 18 (b).—Time distribution of directions in south-east and south-west quadrants (Dec. 1955) in summer.

The results of these observations for January 1957 are shown in Figure 19. It will be seen that the east-west component appears to reverse again about midnight.

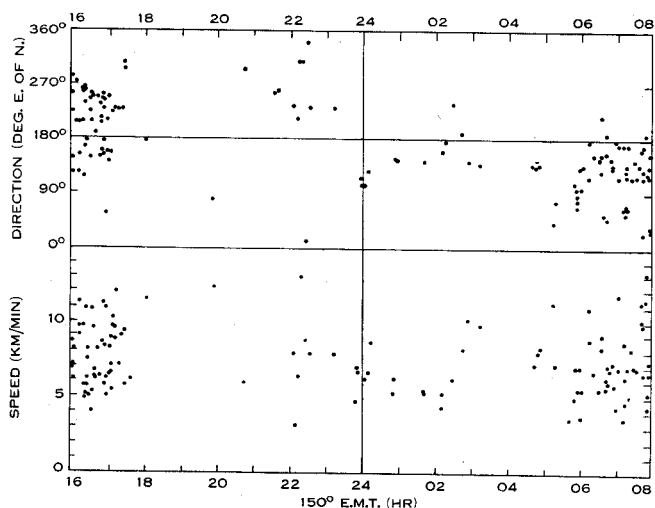


Fig. 19.—Summer night directions and speeds of travelling ionospheric disturbances, January 1957.

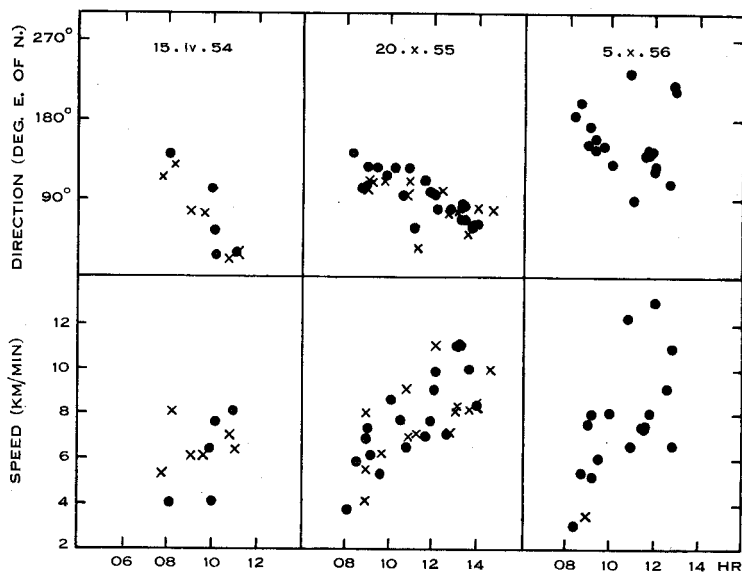


Fig. 20.—Diurnal drift of direction, equinoctial months (April 4, 1954; October 20, 1955; October 5, 1956).

(5) *Equinoctial day-time.*—In the equinoctial months, March, April, September, and October, directions generally show an irregular day-to-day fluctuation between summer and winter tendencies, with the new directions

progressing from a minority to a majority of days. The total change in direction is greater in the September-October equinox and seems to take place more rapidly. A clear mean diurnal variation would therefore seem unlikely and has not been found. There are, however, occasional days on which there is a

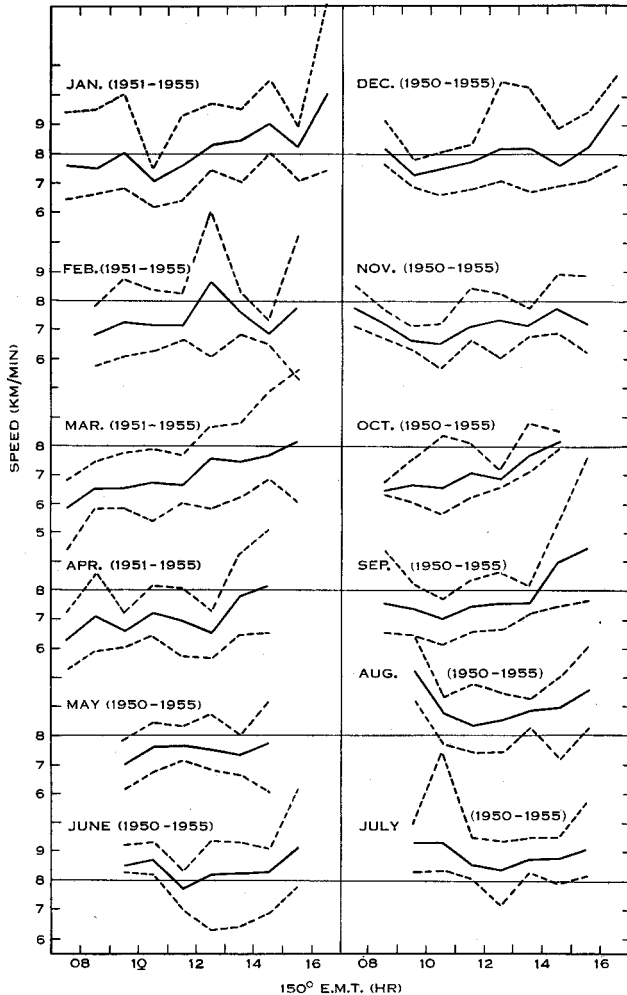


Fig. 21.—Diurnal variations of speed. Mean of medians for each hour.

consistent drift. Three such cases are shown in Figure 20 for the days April 15, 1954, October 20, 1955, and October 5, 1956. In each case the drift is in the same direction, i.e. anticlockwise.

(ii) *Speed*.—Diurnal variations of speed have been small, with little change from year to year. The mean of the medians for each hour of day-time observation during each month are shown in Figure 21, with the maximum deviations shown dotted. There does appear to be a consistent increase of the order of 30 per cent. in mean speed during the day, except in the winter.

The night values show little change from the day values for the corresponding seasons as can be seen in Figures 15 and 19.

It is of interest to note that, in the equinoctial days shown in Figure 20, where the direction has shown a definite drift from summer to winter directions the speed has also shown a corresponding drift from lower summer values to higher winter values. This is in agreement with the trend of the mean curves in Figure 21.

#### V. CONCLUSION

These observations have been all on a single frequency and therefore within a limited range of heights, which itself may have seasonal and sunspot variations. Examination of records has so far not shown any change of direction or speed with height. There do, however, appear to be variations in frequency of occurrence with height. Some indication of this from  $h'f$  records is given in a paper by Heisler (1958) in this issue, and further observations are in progress to provide accurate information using two or three fixed frequencies which will be reflected at different heights. These latter observations will also give information on the slope of front of disturbances, as discussed by Munro and Heisler (1956), that is, the ratio of vertical to horizontal components of travel.

Improved techniques are also being used to give more complete information on diurnal changes. Studies of the dimensions and distance of travel of disturbances are also being continued. It is not proposed, therefore, to discuss in this paper the physical interpretation of the results.

The conclusions reached in Sections III and IV may be summarized as follows.

The mean number observed has been approximately six per day. The actual number recorded varies considerably from day to day. There is a marked maximum of occurrence about midday and possibly a smaller maximum at midnight. This maximum appears to have two peaks, one mainly in summer before noon and the other mainly in winter just after noon. Both peaks show clearly at the equinoxes. There is also a seasonal variation of occurrence with minima at the equinoxes.

Directions of travel have considerable scatter, but on most days a significant mean is deducible. This mean direction also shows some variation from day to day, but monthly median directions are significant and consistent from year to year.

There is a definite seasonal change of mean day-time direction from approximately  $30^\circ$  in winter to approximately  $120^\circ$  in summer, the change taking place more rapidly at the vernal equinox.

The winter diurnal variation has shown a consistent drift from approximately  $60$  to  $20^\circ$  between 0800 and 1600 hr, apparently continuing into the north-west quadrant at night.

In summer until recently there has been little variation during the day, but the very limited night observations suggest a change from the south-east quadrant by day to the south-west quadrant at night. During the last two summers,

however, there has been a definite change to the south-west quadrant near midday and a return change about midnight.

The variations in speed are not great. The scatter of values is found to have a normal probability distribution when examined on a monthly or yearly basis.

The mean monthly speed varies only between 7 and 9 km/min, with a main maximum in winter and a smaller one in summer, and approximately equal minima at the equinoxes. This variation is similar in form to that of occurrence. Ninety-eight per cent. of observed values fall between 3 and 20 km/min and the median value is 6 km/min.

The mean total day-time diurnal variation of speed is of the same order as the seasonal variation, showing a rise of approximately 2 km/min from 0800–1600 hr in the months from January to April and September and October.

Little correlation with other geophysical data has yet been found but the change in diurnal variation of direction during the last two summers suggests a connexion with sunspot activity.

#### VI. ACKNOWLEDGMENTS

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